

From Compaction to Cultivation: Worms and White Clover as Nature Based Solutions for Urban Soil Decompaction

By Dr. Glynn Percival



Soil compaction caused by anthropogenic activities, (infrastructure installation and maintenance, urban development, pedestrian and vehicular traffic) are recognized as a major constraint to urban tree health. For this reason, Dr Glynn Percival will discuss the results of a five-year project aimed to develop a nature-based solution for de-compacting urban soils.

Introduction

The study was conducted at Stockley Park (Latitude: 51° 30' 36.00" N Longitude: 0° 26' 38.40" E), between 2017-2020. Stockley Park is a 111 hectare business park containing over 140,000 trees and shrubs located in the London Borough of Hillingdon in the U.K. For comparative purposes Central Park located in New York is 341 hectare while the Golden Gate Park, located in San Francisco is 412 hectares. Initially focused on basic maintenance, the park's management has evolved to include proactive initiatives such as composting and green waste disposal, the development of wildflower meadows, the creation of improved natural habitats like 'floating islands' (a mass of floating aquatic plants, mud, and peat ranging in thickness from several centimeters to a few meters), and continuous efforts to enhance and improve the park's landscape.

Despite these efforts, Stockley Park faces several environmental challenges typical of highly manicured urban landscapes. These include soil compaction from landscape and construction machinery as well as pedestrian traffic, limited water infiltration and soil volumes leading to drought conditions, and elevated atmospheric pollutants from vehicular traffic. These environmental stresses have adversely affected the health and vitality of the planted trees and shrubs, resulting in poor canopy coverage, limited stem extension growth, sporadic branch, stem, and leaf die-back, stem lesions, and yellowing and chlorotic leaves. Additionally, weakened trees have become susceptible to pest attacks, such as those from the horse chestnut leaf miner and oak processionary moth where heavy and frequent outbreaks have been recorded.



Photo 1: Blue cedars forming part of the visual landscape at Stockley Park.



Photo 2: Vista of maples providing shade and windbreak functions.



Photo 3: Declining maple trees due to soil compaction caused by parked cars.



Photo 4: Symptoms of leaf yellowing/chlorosis caused by soil compaction.

In such scenarios, the common practice among business parks is to wait until a tree no longer provides aesthetic or functional benefits or is deemed structurally unsound and poses a potential hazard to traffic, buildings, and pedestrians, before removing it. This approach is usually adopted as this is perceived as the most cost-effective approach in these situations. However, this approach is flawed as it eliminates the numerous functional benefits trees offer, such as providing shade, deflecting and absorbing noise, reducing wind velocity and solar glare, filtering dust and ultraviolet light, and absorbing vehicular pollutants. Additionally, the removal and replanting of large trees can be more costly and labor-intensive than anticipated, which are likely what the landowners sought to avoid by pursuing this strategy in the first place.

To address these issues, the Bartlett Tree Research Laboratory has developed a proactive, sustainable, and holistic approach to tree and shrub care tailored to this business park. This approach aims to remediate the aforementioned problems, while being as environmentally benign as possible.

Site Assessment

It is now recognized that 80-90% of above-ground tree problems (e.g., yellowing leaves, canopy die-back) are caused by below-ground issues (Percival et al 2023). Consequently, over one hundred soil samples were collected throughout Stockley Park and analyzed for their macro (N, P, K, Ca, Mg,) and micronutrient (Fe, Cu, B, Na, Mn) content, pH, heavy metals, and organic matter content. Additionally, soil compaction levels were determined using bulk density analysis, and soil biology was assessed by examining the degree of root/mycorrhizal association and the number of worms per square meter of soil, a measure of soil fertility. (Ahmed and Al-Mutairi, 2022)

Based on these analyses, several soil-related problems were identified throughout the park:

Soil Analysis:

- pH values are too high (7.1-8.9, with the optimum being ~6.5)
- Low levels of potassium, nitrogen, calcium, and magnesium
- High salinity levels due to excessive sodium (Na+) ions (high conductivity values)
- High sand content leading to a low Cation Exchange Capacity
- Low organic matter leading to low overall fertility

Compaction Analysis:

- High soil compaction levels (1.7-1.9; for comparison, fire brick = 2.2)
- Trees were planted too deep

Soil Biology:

- Absence of worms
- No or limited mycorrhizal root association



Photo 5: Removal of soil samples for nutrient analysis.

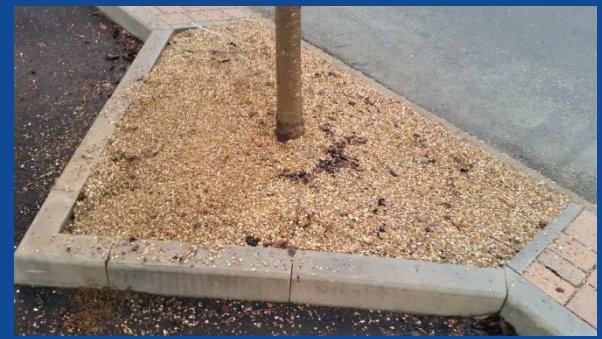


Photo 6: Symptoms of deep planting.

Worms

In woodland and forest environments, soil de-compaction naturally occurs due to the activity of subterranean organisms and fauna. Among the common subterranean organisms in the UK are earthworms, often referred to as “ecosystem engineers” due to their significant roles in pedogenesis (soil formation), decomposition, and nutrient recycling. The use of earthworms by humans for composting and enhancing soil fertility in agricultural land has been a longstanding practice.

Earthworms consume leaf mold, decomposing wood particles, dead insects, and organic matter. As these materials pass through their digestive systems, they are broken down and excreted as worm castings, which are a biological form of nitrogen readily available to plants. Upon their death, earthworm carcasses contribute to the organic matter in the soil, further enhancing soil fertility and structure. Additionally, earthworms loosen compacted soil and improve its structure by creating tunnels and burrows, which aerate the soil and facilitate water percolation. As they feed, earthworms transport materials to new locations before excreting them, resulting in the constant churning of both organic and inorganic materials throughout the soil profile. Earthworms can enhance soil porosity by up to 400% (AHDB, 2019).

The practice of introducing earthworms for soil de-compaction in urban landscapes has received little attention. In this study, two species of native earthworms, *Dendrobaena veneta* and *Lumbricus terrestris*, were used. Each species operates in different planes within the soil, with *L. terrestris* moving vertically and the *D. veneta* horizontally, providing a mixing action down to a depth of 1 meter. Earthworms were obtained commercially

in boxes, each containing 50 earthworms and spaced 3 meters apart. The earthworms were removed from the boxes and placed into 45 cm wide by 45 cm deep holes, which were then gently backfilled with soil and thoroughly watered.



Photo 9: Trail set up just before addition of worms.



Photo 10: Soil amendment with worms.

White Clover Cropping

Trifolium repens L., commonly known as white clover, is a stoloniferous, perennial plant renowned for its ability to symbiotically fix atmospheric nitrogen (N). This species has been widely utilized in agriculture and more recently in forestry as a sustainable alternative to synthetic nitrogen fertilizers. Under optimal conditions, white clover can achieve nitrogen fixation rates ranging from 600 to 700 kg N/ha/year. Additionally, white clover can indirectly enhance crop yields when used as a cover crop by promoting arbuscular mycorrhizal fungi infection, as well as increasing populations of ammonium-oxidizing bacteria and phosphorus-solubilizing microbiota. White clover has also been identified as an ideal “living mulch” for planting between rows of fruit bushes or trees, particularly in urban landscapes where it can withstand harsh edaphic conditions. As a perennial nitrogen producer, white clover possesses a dense, shallow root system that protects soil from erosion and suppresses weed growth. Furthermore, white clover mulch has been shown to reduce soil compaction and dust generated by vehicular traffic. This plant has the potential to transform exposed bare soil into biologically active soil, providing a habitat for beneficial organisms both above and below the soil surface. Despite the lack of studies on the impact of white clover cover crops on soil biology in urban tree environments, a five-year study demonstrated that white clover sown between rows in an organic peach orchard significantly improved root density, earthworm populations, water infiltration rates, nitrogen content, and water availability. In silvopastoral systems, which integrate tree and pasture production, white clover has proven to be an effective species for promoting tree growth (López-Díaz et al., 2009). Until now, however, its potential to enhance biological activity and soil fertility in compacted urban soils remains unexplored.

The Challenge: Development of A Long-Term Nature Based Soil De-Compaction System

Given that Stockley Park spans 60 hectares, with 50-60% designated as greenspace, de-compacting the entire landscape was neither economically nor practically feasible. Therefore, the challenge was to develop a nature-based solution (NBS) to remediate soil compaction and enhance soil quality/fertility, specifically decompact 100 square meter areas throughout the 60-hectare site and amend the soil in such a way that the surrounding compacted areas would naturally de-compact over time. Areas of 100 sq meters was chosen based on ease of marking out and convenience in de-compacting. A NBS is defined “As an action that incorporates natural features and processes to protect, conserve, restore, sustainably use, and manage natural or modified ecosystems to address socio-environmental challenges while providing measurable co-benefits to and benefit both people and nature.” NBS implementation can be referred to as “green infrastructure” or “natural infrastructure.”

The importance of this to landscape managers is that in April 2022, Executive Order 14072 by the US Department of the Interior directed the federal government to accelerate our use of solutions that are grounded in nature, specifically calling for the deployment of NBS to improve the resilience of our lands, waters, wildlife, and communities in the face of climate change and other natural disasters.

The agreed-upon NBS process involved vertical mulching:

Vertical Mulching Process:

- Soil cores (7.5 cm wide, 30 cm deep) were removed at 50 cm intervals under the tree crown. The removed soil cores were disposed of, and the resulting holes were refilled with one of the following mixtures:
 1. Biochar (5%) + John Innes No 3 soil (92%; a high quality commercially available (sandy loam, peat, horticultural sand (7:3:2) top soil) + slow-release organic fertilizer (3%), covered with a 5 cm layer of wood chip mulch.
 2. Biochar (5%) + John Innes soil (92%) + slow-release organic fertilizer (3%) + worms (*Dendrobaena veneta* and *Lumbricus terrestris*. *L. terrestris* applied at a density of 8 worms per meter squared of soil to a depth of 5cm), covered with a 5 cm layer of wood chip mulch.
 3. Biochar (5%) + John Innes soil (92%) + slow-release organic fertilizer (3%) + area sown with clover (*Trifolium repens*) sown at the manufacturer recommended rate of 1.5g per square meter.
 4. Biochar (5%) + John Innes soil (92%) + slow-release organic fertilizer (3%) + worms + area sown with clover.
 5. Control: No cores were removed, and the ground remained compacted.

Although vertical mulching is rarely considered by professionals managing urban trees due to potential root system damage from soil core removal, it was used in this case for two reasons:

1. The high degree of soil compaction meant there was little root growth within the compacted area at the trial's onset, and therefore root damage was unlikely.
2. Vertical mulching allowed for the de-compaction of eight square meters of ground compared to one square meter using an air-spade, representing a substantial savings in both time and labor.



Photo 7: Instigation of vertical mulching trial.



Photo 8: Vertical mulching trial prior to addition of wood chip over the soil surface.

Tree Health

Three tree species were utilized for experimental purposes: Field maple (*Acer campestrepp.*), small-leaved lime (*Tilia cordata*), and white-flowering horse chestnut (*Aesculus hippocastanum*), with a minimum of ten trees per treatment (refer to Photographs 11-12).

Tree health was monitored over a three-year period, assessing various parameters including leaf size, leaf color (greenness) using a leaf chlorophyll content (SPAD) meter, leaf photosynthetic efficiency via chlorophyll fluorescence, stem extension, girth increment, crown canopy coverage, root growth, mycorrhizal status, and soil respiration rates.

Results

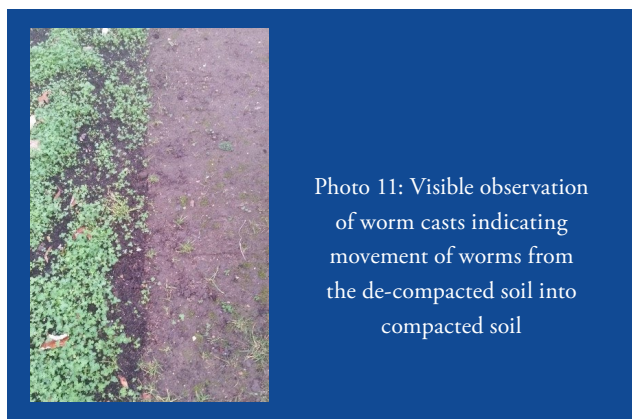
Root Density

It is beyond the scope of this article to discuss all results to date. However, the objective of these studies was to develop a system where, once an area was de-compacted, the soil microbial and subterranean fauna would effectively expand into the surrounding compacted soil, thereby creating more favorable soil conditions for root growth. Consequently, only data for root density within the de-compacted area (i.e., under the canopy) and the non-de-compacted area (i.e., one meter beyond the canopy drip line) are presented in Table 1.

Table 1. The Influence of Vertical Mulching, Wood Chip Mulch, Worms and Clover on Root Density of Lime.

	Root Density (dry mass g per cm ³)	
	Under the canopy (de-compacted soil)	1 metre outside the canopy area
No treatment (control)	0.0019	0.0011
Vertical Mulching + Wood Chip	0.0244	0.0008
Vertical Mulching + Wood Chip + Worms	0.0218	0.0311
Vertical Mulching + Clover	0.0324	0.0009
Vertical Mulching + Clover + Worms	0.0220	0.0187

The results presented in Table 1 demonstrate that all de-compaction systems significantly enhanced root density, regardless of the presence of earthworms. However, it is noteworthy that only treatments involving the addition of earthworms had a significant impact on root density beyond the treated area. Photograph 11 clearly illustrates the presence of worm casts outside the treated zone, indicating that earthworms are migrating from the de-compacted soil into the non-de-compacted soil. This movement creates more favorable subsoil conditions for future root growth (Photograph 12).



Canopy Growth



Photo 13: Untreated lime (left hand side) Vs treated lime (right hand side)



Photo 14: Treated horse chestnut (left hand side) Vs untreated horse chestnut (right hand side)

Photographs 13-14 illustrate the outcomes of de-compaction treatments after three years, including improved visual appearance, enhanced crown coverage and root growth, reduced leaf yellowing and chlorosis, improved leaf photosynthetic efficiency, increased stem extension and girth increments, and reduced crown die-back.

The functional benefits of increased canopy coverage (Photograph 15) resulting from de-compaction treatments were quantified as follows: increased shade and UV protection, enhanced CO₂ sequestration and oxygen production, and improved removal of particulate matter (1-10 µg/cm² leaf area) and atmospheric heavy metals (cadmium, chromium, zinc, lead, nickel, copper). This is evident in Photograph 15, where soil de-compaction has led to larger canopy coverage (circled area). This additional canopy growth alone corresponds to an extra 0.4 kg of CO₂ sequestered and 2.2 kg of O₂ produced per year, 4.0 mg of particulate matter removed per day, 28% more UV protection, and the removal of cadmium (0.2 mg), chromium (0.4 mg), zinc (3.9 mg), lead (12.0 mg), nickel (2.3 mg), and copper (8.0 mg) each growing season. These increased benefits have raised the assigned monetary value of the tree to £2.2K, compared to £1.3K for the control tree on the left, which more than offsets the de-compaction costs of approximately £80-120 per tree.



Photo 15: Increase in crown canopy area caused by soil de-compaction and subsequent enhanced root growth.

Conclusions

This study evaluated the impact of two nature-based soil decompaction methods—using earthworms and white clover cropping—alongside traditional techniques like vertical mulching and woodchip mulching on soil quality and tree growth. All methods reduced soil compaction and improved soil quality and tree growth, but there were notable differences between treatments. The most effective approach combined traditional methods (vertical mulching and woodchip mulch) with a nature-based solution involving earthworm soil amendment. Over three years, this combination significantly enhanced the physical, chemical, and biological properties of compacted urban soil. Additionally, soil compaction decreased over time, partly due to earthworm migration. The findings highlight a sustainable soil decompaction method that offers arborists a nature-based option to improve compacted urban soils. This treatment notably boosted root and canopy growth, enhancing the ecosystem benefits provided by trees and potentially mitigating the adverse effects of global climate change. Importantly the use of a NBS as discussed in this article provided a long-term sustainable cost-efficient and effective treatment for i) alleviating soil compaction, improving soil quality, and stimulating tree growth in a compacted urban soil ii) provide an innovative approach to maintain or restore the declining soil ecosystem services. The use of a NBS would prove in the long term a more cost effective remediation system compared to current technologies which rely heavily on the use of machinery to physically break up compacted soils. 🌱

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